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Influence of the Asymmetry of Optical Transitions in a Three-Level Atom on the CPT-resonance

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ABSTRACT

The characteristics of CPT-resonance, i.e. its width, depth and contrast, are considered for the three-level Λ-atom interacting with two resonant monochromatic radiation fields. We develop the compurter simulation to investigate the influence on these characteristics of the asymmetric properties of medium: inequality of the dipole moments and inequality of the relaxation rates of population. Both weak and strong radiation fields are considered. For the weak fields the inequality of the Rabi-frequencies is found to influence weakly or even not to influence on the CPT-resonance shape. For the strong fields we found the significant influence of the asymmetry on the shape. We conclude that the CPT-resonance in the strong fields can be utilized as a tool for measure of the optical transitions assymetry. As an example of the real system interacting with two strong radiation fields we consider the characteristics of the CPT-resonance for the magnetic sublevels of states $6P_{1/2}$, $6P_{3/2}$ and $7S_{1/2}$ for Tl-atom.

Keywords: width, depth and contrast of CPT-resonance; strong and weak laser fields; homogeneous magnetic field; Tl-atom.

The measuring of the characteristics of the CPT-resonance shape (i.e. width, depth and contrast of the dip on the line profile) is mostly provided for the weak radiation fields in the experiments and theoretically. In the paper [1] the simple equations for the approximate estimation of the characteristics are represented without taking into account the asymmetry of the optical transitions (inequality of their characteristics). These equations work well for the weak radiation fields, and as shown in [2, 3] are not appropriate for the strong fields.

The influence of the asymmetry of the atomic optical transitions on the CPT-resonance was considered theoretically by Kocharovskaya in [4] for the three-level system interacting with the sequence of the ultra-short pulses. The inequality of the electric dipole moments was taken into account. The decay rates of the upper level population and of the coherences assumed to be the same, that is not always takes place. These conditions correspond, for example, to the case of the strong influence of the particles collisions in a gas.

In this paper we present the numerical study of the CPT-resonance shape at the unequal dipole moments and decay rates of the upper level population both for the strong and for the weak radiation fields. We consider the simple three-level atom that interacts with two resonant monochromatic fields and with homogeneous magnetic field. In addition, we consider the system of levels of Tl-atom for the strong radiation fields. We develop the numerical procedure for measuring of the CPT-resonance width, depth and contrast and consider the dependence of these characteristics on the different parameters. The parameters are the Rabi frequencies, intensities of the laser radiation fields, the partial decay rates of the upper state population, the relation of the spontaneous decay rates, and the decay rates of the low-frequency coherency.

To study the CPT effect in the strong radiation fields we consider the definite system of levels of Tl atom. The real properties of this system are taken into account: unequal electric and magnetic dipole moments and unequal partial rates for the spontaneous decay of the upper state.

Let us consider the Λ-system of the levels $6P_{1/2}$, $6P_{3/2}$ and $7S_{1/2}$ of Tl atom (Fig. 1) that interacts with two strong radiation fields and constant magnetic field. The fields have the following directions:

$$\mathbf{H} \uparrow\uparrow \mathbf{e}_{L1} \uparrow\uparrow \mathbf{e}_{L2} \uparrow\uparrow Oz,\ H \perp k_{L1} \perp k_{L2},$$

where e_{L1}, e_{L2}, k_{L1} and k_{L2} are the unit vectors of polarization and the wave vectors of the first and second fields of the radiation, respectively. For this orientation of the fields it is possible to separate the chosen system of levels and obtain two independent three-level Λ-systems consisting of Zeeman sublevels $6P_{1/2}(m=1/2)$, $6P_{3/2}(m=1/2)$, $7S_{1/2}(m=1/2)$ and

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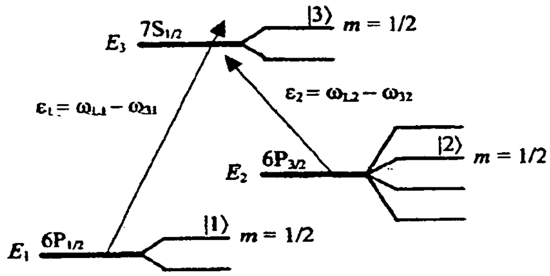

Fig. 1. The scheme of the considered levels and transitions in thallium. ω_{31} and ω_{32} are the frequencies of $6P_{1/2} - 7S_{1/2}$ and $6P_{3/2} - 7S_{1/2}$ transitions. ω_{L1} and ω_{L2} are the frequencies of the laser fields. $|1\rangle$, $|2\rangle$, $|3\rangle$ are the considered states of the atom, when it does not interacts with radiation fields.

$6P_{1/2}(m=-1/2)$, $6P_{3/2}(m=-1/2)$, $7S_{1/2}(m=-1/2)$. It is enough without restrictions to consider the only one of these systems, to be specific with the magnetic quantum number $m = 1/2$. The other one having the magnetic quantum number $m=-1/2$ is obviously identical.

We consider the levels of Tl in the strong radiation fields ($I_{L1,L2} = 10^3 \div 10^7\ \mathrm{W/cm^2}$) and hence the superfine structure of the levels is neglected. The following characteristic that correspond to a real system are taken into account: the unequal electric dipole moments and the unequal partial spontaneous decay rates of the upper state. The decay to the state $6P_{3/2}(m=3/2)$ is neglected. This is main restriction of the system under consideration.

The Hamiltonian of the considered system of levels has the following form:

$$\mathcal{H} = \mathcal{H}_0 + V_{int}, \tag{1}$$

where $\mathcal{H}_0$ is the Hamiltonian of free atom with eigen wave functions describing the states $6P_{1/2}$, $6P_{3/2}$ and $7S_{1/2}$ of Tl that are degenerated in m. The Hamiltonian of interaction V_{int} contains the interaction of the atom with two monochromatic laser radiations and the inhomogeneous constant magnetic field. Neglecting the quadratic terms, one can write

$$V_{int} = -\frac{e\hbar}{2mc}\left[(L+2S)H\right] - \frac{e}{mc}\,p\,A_R, \tag{2}$$

$$A_R = A^0_{L1}\exp\left(-i\omega_{L1}t + kr\right) + A^0_{L2}\exp\left(-i\omega_{L2}t + kr\right) + \text{c.c.}, \tag{3}$$

where A_R is the vector-potential of laser radiations, H is the magnetic field strength, p is the operator of momentum, $(e\hbar/2mc)(L+2S) = \mu$ is the atom magnetic moment operator, and ω_{L1} and ω_{L2} are the frequencies of the first and the second laser fields, respectively.

To describe the interaction we use the density-matrix formalism:

$$\left(\frac{\partial}{\partial t} + \mathbf{v}\nabla\right)\rho_{nm} = \Gamma_{nm} - \frac{i}{\hbar}\sum_{j=1}^{3}\left[V_{mj}\rho_{jn} - \rho_{mj}V_{jn}\right] \quad n,m = 1,2,3, \tag{4}$$

where V_{mj} is the matrix element of the interaction operator, Γ_{mn} are the decay rates, and $\mathbf{v}$ is the atom velocity that we assume to be zero. The set of equations for the density matrix elements for the considered system of levels can be written as

$$\frac{\partial \rho_{11}}{\partial t} = g_1\rho_{13} + g_1^*\rho_{31} + \gamma_1\rho_{33}$$

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$$
\begin{aligned}
\frac{\partial \rho_{22}}{\partial t} &= g_2\rho_{23} + g_2^{*}\rho_{32} + \gamma_2\rho_{33} \\
\frac{\partial \rho_{33}}{\partial t} &= -g_1\rho_{13} - g_2\rho_{23} - g_1^{*}\rho_{31} - g_2^{*}\rho_{32} - (\gamma_1+\gamma_2)\rho_{33} \\
\frac{\partial \rho_{13}}{\partial t} &= \left(i m_1 - i m_3 - \frac{1}{2}(\gamma_1+\gamma_2) - \Gamma_1 - i\varepsilon_1\right)\rho_{13} - g_2^{*}\rho_{12} + g_1^{*}(\rho_{33}-\rho_{11}) \\
\frac{\partial \rho_{23}}{\partial t} &= \left(i m_2 - i m_3 - \frac{1}{2}(\gamma_1+\gamma_2) - \Gamma_2 - i\varepsilon_2\right)\rho_{23} - g_1^{*}\rho_{21} + g_2^{*}(\rho_{33}-\rho_{22}) \\
\frac{\partial \rho_{12}}{\partial t} &= (i m_1 - i m_2 - \Gamma - i(\varepsilon_1-\varepsilon_2))\rho_{12} + g_1^{*}\rho_{32} + g_2\rho_{13},
\end{aligned} \tag{5}
$$

Here $g_1 = \left(R_{1/2}^{1/2}A_{L1}^{0}\right)/\left(\hbar c\lambda_{13}\sqrt{6}\right)$ and $g_2 = \left(R_{3/2}^{1/2}A_{L2}^{0}\right)/\left(\hbar c\lambda_{23}\sqrt{6}\right)$ are the Rabi frequencies. A_{L1}^{0}, A_{L2}^{0} are the amplitudes of vector-potential of the radiation. $R_{1/2}^{1/2}$, $R_{3/2}^{1/2}$, λ_{13}, and λ_{23} are the reduced matrix elements of the operator of the electric dipole moment and the wave lengths for transition $6P_{1/2}-7S_{1/2}$ and $6P_{3/2}-7S_{1/2}$, respectively. $m_1 = \left(\mu_{1/2}^{1/2}H\right)/\left(\hbar 2\pi c\sqrt{6}\right)$, $m_2 = \left(\mu_{3/2}^{3/2}H\right)/\left(\hbar 2\pi c 2\sqrt{15}\right)$, $m_3 = \left(3\mu_{1/2}^{1/2}H\right)/\left(\hbar 2\pi c\sqrt{6}\right)$ are the magnetic coefficients. $\mu_{1/2}^{1/2}$ and $\mu_{3/2}^{3/2}$ are the reduced matrix elements of the operator of the atom magnetic moment for states $6P_{1/2}(m=1/2)$ and $6P_{3/2}(m=1/2)$, respectively. $\varepsilon_i = \omega_{2i} - \omega_{3i} (i=1,2)$ are the frequencies detunings of the laser fields. γ_i $(i=1,2)$ are the partial decay rates of the population of the level $|3\rangle$ to the levels $|1\rangle$ and $|2\rangle$. Γ, Γ_1 and Γ_2 are the decay rates of coherence of ρ_{12}, ρ_{23} and ρ_{13}, respectively. In the situations where $\Gamma_{1,2}=0$ the decay rates $\gamma_{1,2}$ are considered being spontaneous. Equation for ρ_{31}, ρ_{32} and ρ_{21} are complex conjugated to the equation for ρ_{13}, ρ_{23} and ρ_{12}, respectively.

The set of equations (5) is known well. We have derived it for the definite system of levels, but for other three-level systems it is valid too. Hence we can develop our analysis without specifying the concrete level system both for strong and for weak fields. (For the weak fields the system of levels is usually composed of the levels of superfine structure.)

To obtain the CPT-resonance one needs to consider the steady state solution of (5) $\partial\rho_{ij}/\partial t = 0$ for ρ_{33}. The profiles $\rho_{33}(\varepsilon_1)$, $\rho_{33}(\varepsilon_2)$ and $\rho_{33}(H)$ have the central or side dip that is referred to as CPT-resonance. This dip may be characterized by the width, depth and contrast that are the subject of our interest. We consider the central dip only, when the resonance profile is symmetric. This case is simpler for the analysis and can easily be observed in the experiments.

Let p denotes one of the parameters, i.e. ε_1, ε_2 or H, for which the resonance profile, i.e. $\rho_{33}(p)$, is drawn, and let $\mathcal{P}$ denotes one of the other parameters that is varied to observe the respective variation of the dip when all the rest parameters are constant. To measure the characteristics of the dip for every definite value of $\mathcal{P}$ we find the deepest minimum of the profile $\rho_{33}(p)$ that is the bottom of the dip and two nearest symmetric peaks. Then we define the width as a distance between the inner peaks declivities in the middle between the dip bottom and peaks top. The depth is measured as a distance from the top of the peaks to the dip bottom, and the contrast is calculated as a relation of the depth to the absolute height of the peaks.

The behavior of the CPT-resonance characteristics is studied well for the weak radiation fields of intensity $I_{L1,L2} = 1 \div 100$ mW/cm^2. As discussed by Akulshin at al in [5], when the intensity of radiations decreases the width of the dip decreases to some value and then does not change. Agap'ev at al in [1] suggest the approximate equation for the dip width versus the basic parameters (the Rabi frequencies g, the spontaneous decay rates of the upper state γ, decay rate of the low-frequency coherency Γ):

$$
\Delta \approx \Gamma + g^2/\gamma. \tag{6}
$$

Note that the width is proportional to g^2 (or I_L) when the fields are weak.

The equations (5) have the same form both for the system of levels of superfine structure in the weak fields and for the levels of the fine structure in the strong fields. Hence we can study the CPT-resonance form characteristics for the wide range

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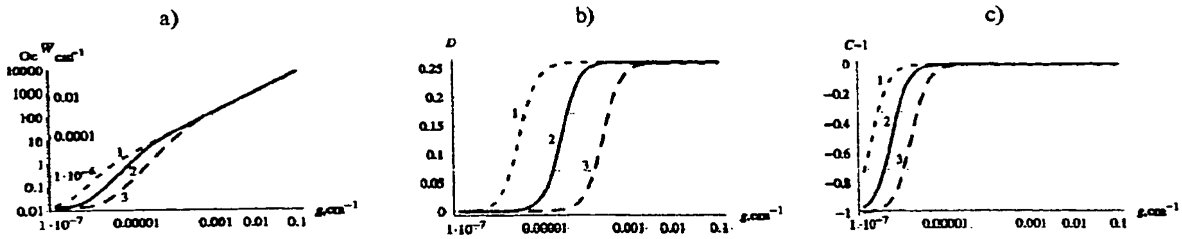

Fig. 2. The dependence of CPT-resonance width W, depth D and contrast C vs. the Rabi frequency g ($g_1 = g_2 = g$). The partial spontaneous decay rates of the upper state population are equal, $\gamma_1 = \gamma_2 = \gamma/2$. (1) $\gamma = 10^{-5}$ cm^{-1}, (2) $\gamma = 10^{-4}$ cm^{-1}, (3) $\gamma = 10^{-3}$ cm^{-1}. The decay rate of low frequency coherence Γ is taken very small, 10^{-8} cm^{-1}. $\Gamma_1 = \Gamma_2 = 0$. On the figure (a) the left vertical axis corresponds to the dip on the profile $\rho_{33}(H)$, and the right axis corresponds to the profile $\rho_{33}(\varepsilon_2)$ at $\varepsilon_1 = 0$.

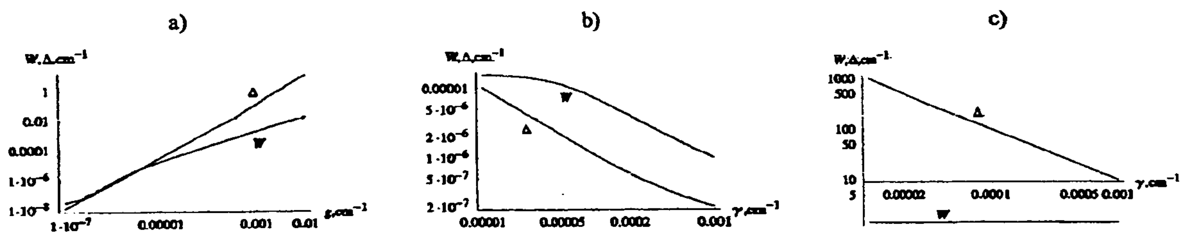

Fig. 3. The width of the CTP-resonance calculated numerically, W, and obtained from Eq. (6), Δ, vs. (a) the Rabi frequency g, (b, c) the spontaneous decay rate γ of the upper state. For all cases $g_1 = g_2 = g$, $\gamma_1 = \gamma_2 = \gamma/2$. Δ is found from Eq. (6). W is found on the profile $\rho_{33}(\varepsilon_2)$ (the first field detuning is $\varepsilon_1 = 0$). The decay rate of low frequency coherence Γ is taken smallest, $\Gamma = 10^{-8}$ cm^{-1}. $\Gamma_1 = \Gamma_2 = 0$. (a) $\gamma = 10^{-5}$ cm^{-1}. (b) $g = 10^{-5}$ cm^{-1}. (c) $g = 0.1$ cm^{-1}.

of the Rabi frequencies at the different spontaneous decay rates without specifying of the system of the atomic levels. We assume for this purpose that the Rabi frequencies for the optical transitions and the partial spontaneous decay rates are equal, $g_1 = g_2 = g$, $\gamma_{1,2} = \gamma/2$. The results of calculations are presented in Fig. 2. The marks on the left vertical axis of Fig. 2(a) correspond to the width of the dip on the profile $\rho_{33}(H)$ (For these calculations the coefficients m_i are taken about $10^{-5}(\mathrm{cm}\cdot\mathrm{Oe})^{-1}$, that corresponds to system of levels of Tl-atom.) The right vertical axis corresponds to the dip on the profile $\rho_{33}(\varepsilon_2)$. There are three regions on the obtained curves for all considered values of γ. The first one corresponds to the low intensity of radiation. The width W is rather constant, the depth D and the contrast C are small. In the second region $W \sim g^2, I_L$, D and C grow with the intensity. (The exponent 2 is founded as a slope of the line that approximates well the curve in the double logarithmic scale in this region.) All these values are very sensitive to the spontaneous decay rate. As shown in Fig. 3(a) in this region the width is described well by the equation (6). The third region corresponds to the strong radiation fields that saturate the optical transition. Here $W \sim g, I_L^{0.5}$, D and C tends to some asymptotic value. All the values are not very sensitive to the spontaneous decay rate.

In Fig. 3 one can see the dependence of the width on the spontaneous decay rate γ. The numerically calculated width W is compared with Δ obtained from Eq. (6). One can see from Fig. 3(b) that $W(\gamma)$ and $\Delta(\gamma)$ are similar if the radiation fields

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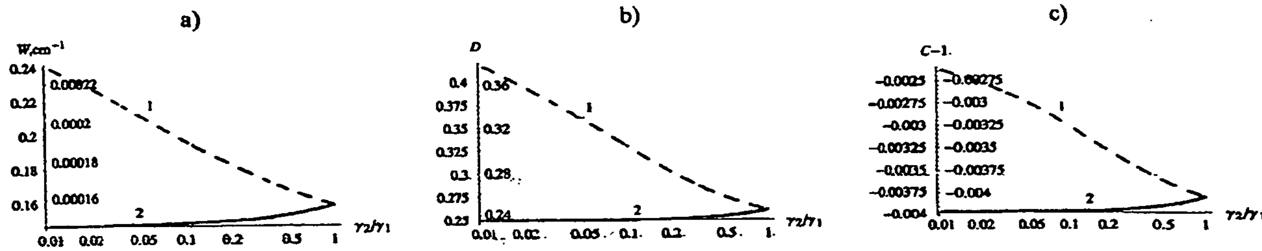

Fig. 4. The dependence of the width W (a), depth D (b) and contrast C (c) of CPT-resonance on the relation of the decay rates γ_2/γ_1 (at $\gamma_1+\gamma_2=\gamma$). $\gamma=10^{-4}\mathrm{cm}^{-1}$, $\Gamma=10^{-7}\mathrm{cm}^{-1}$, $\Gamma_1=\Gamma_2=0$. (1) $W, D, C(\gamma_2/\gamma_1)$ on the profile $\rho_{33}(\varepsilon_2)$ at $\varepsilon_1=0$. (2) $W, D, C(\gamma_2/\gamma_1)$ on the profile $\rho_{33}(\varepsilon_1)$ at $\varepsilon_2=0$. The left vertical axis corresponds to $g_{1,2}=10^{-4}\mathrm{cm}^{-1}$, and the right one corresponds to $g_{1,2}=0.1\mathrm{cm}^{-1}$.

are weak. For the intensity about $I_{L1,L2}=10^3\div10^7\mathrm{W/cm}^2$ W changes much slower than Δ versus γ, while the latter decreases as a hyperbole (see. Fig. 3(c)). Hence the equation (6) is not valid as evaluation of the CPT-resonance width in this case. We do not show on a figure the depth and the contrast versus γ. These values decreases fast with growing γ when the fields are weak and for the strong fields they are rather insensitive to γ.

Investigation of dependence of W on the low-frequency coherence decay rate Γ shows that in the weak fields W grows linearly with Γ. The slope of this line is very sensitive to g and γ and it seems to be difficult to suggest some improving correction to the equation (6). For the strong radiation fields ($g=0.1\mathrm{cm}^{-1}$) Γ influences weakly to the width. The depth and the contrast decreases with Γ and attain zero for large Γ. This is not surprising, because the CPT is known to be destructed by the dephasing of low-frequency coherence. This observation corresponds to the known experimental (for example [6]) and theoretical [1] results.

Let us consider the case when the spontaneous decay rates of the upper state $|3\rangle$ population to the state $|1\rangle$ and to the state $|2\rangle$ are different. In Fig. 4 W and D are drawn versus the relation of the decay rates γ_2/γ_1 when their sum is kept constant, $\gamma_1+\gamma_2=\gamma$ and the Rabi frequencies for both transitions are the same. The left vertical axis corresponds to the weak radiation, $g_{1,2}=10^{-4}$ cm^{-1} and the right one represents the strong radiation, $g_{1,2}=0.1\mathrm{cm}^{-1}$.

One can see that the characteristics of the CPT-resonance measured on the profiles $\rho_{33}(\varepsilon_1)$ and $\rho_{33}(\varepsilon_2)$ coincides only when $\gamma_1=\gamma_2$. Simultaneous decreasing of γ_2 and increasing of γ_1 results in the growing of W, D and C on the profile $\rho_{33}(\varepsilon_2)$ and the falling of the these values on the profile $\rho_{33}(\varepsilon_1)$. When, on contrary, γ_2 grows and γ_1 falls one observes the inverse situation. The discussed figure is drawn for $\gamma=10^{-4}\mathrm{cm}^{-1}$ when both the Rabi frequencies correspond to the region $W\sim g^2, I_L$ (see Fig. 2). We see that in this case for the weaker ($g_{1,2}=10^{-4}$ cm^{-1}) and for the stronger ($g_{1,2}=0.1\mathrm{cm}^{-1}$) fields the relation [$W$ for $\rho_{33}(\varepsilon_2)$]/[W for $\rho_{33}(\varepsilon_1)$] is the same. When $g_{1,2}$ correspond to the region $W\sim g^2, I_L$ the relation [W for $\rho_{33}(\varepsilon_2)$]/[W for $\rho_{33}(\varepsilon_1)$] is always very close to 1 and, hence, the influence of the asymmetry is weak. (The same situation can be observed for D and C.) Thus, experimental determination of the CPT-resonance width in the fluorescence spectrum for both radiation fields gives the information about the population decay rate of the atomic transition that is not studied well yet. This can be another one application of the CPT-effect in the strong radiation fields.

Let us now consider the situation where the asymmetry of the optical transitions are determined by the inequality of the electric dipole moments. This inequality and the inequality of the intensities of the radiation fields result in the inequality of the Rabi frequencies. The population decay rates are assumed to be equal which for the real systems can be the result of the influence of the collisions. To obtain this situation we set the partial decay rates $\gamma_{1,2}$ and the decay rates of the coherence

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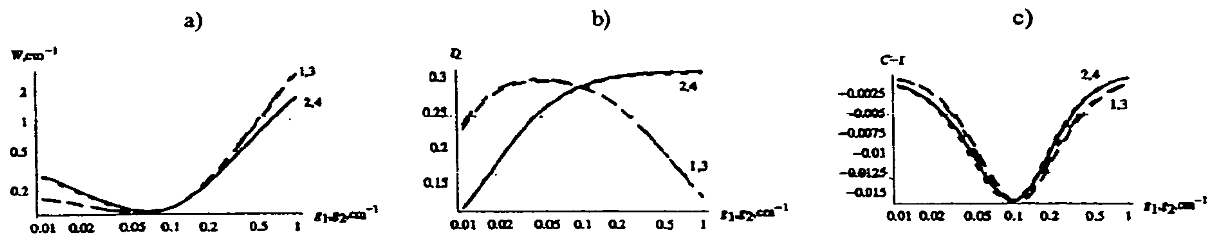

Fig. 5. The dependence of the width (a), depth (b) and contrast (c) of CPT-resonance on the Rabi frequency of one of the optical transitions. (1) $W,D,C\,(g_2)$. Resonance is observed on the profile $\rho_{33}(\varepsilon_2)$, $\varepsilon_1 = 0$, $g_1 = 0.1\text{cm}^{-1}$. (2) $W,D,C\,(g_2)$. Profile $\rho_{33}(\varepsilon_1)$, $\varepsilon_2 = 0$, $g_1 = 0.1\text{cm}^{-1}$. (3) $W,D,C\,(g_1)$. Profile $\rho_{33}(\varepsilon_1)$, $\varepsilon_2 = 0$, $g_2 = 0.1\text{cm}^{-1}$. (4) $W,D,C(g_1)$. Profile $\rho_{33}(\varepsilon_2)$, $\varepsilon_1 - 0$, $g_2 = 0.1\text{cm}^{-1}$. For all cases $\Gamma = 10^{-4}\text{cm}^{-1}$, $\Gamma_1 = \Gamma_2 = \gamma_1 = \gamma_2 = 10^{-2}\text{cm}^{-1}$.

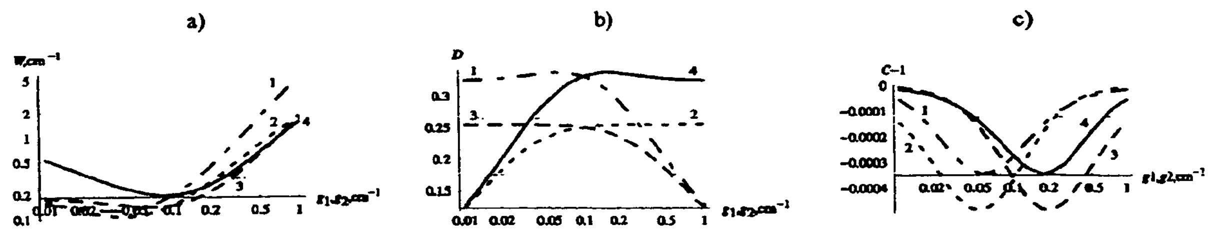

Fig. 6. The dependence of the width (a), depth (b) and contrast (c) of CPT-resonance on the Rabi frequency of one of the optical transitions for the strong laser radiation fields. (1) $W,D,C\,(g_2)$. Resonance is considered on the profile $\rho_{33}(\varepsilon_2)$, $\varepsilon_1 = 0$, $g_1 = 0.1\text{cm}^{-1}$. (2) $W,D,C\,(g_2)$. Profile $\rho_{33}(\varepsilon_1)$, $\varepsilon_2 = 0$, $g_1 = 0.1\text{cm}^{-1}$. (3) $W,D,C\,(g_1)$. Profile $\rho_{33}(\varepsilon_1)$, $\varepsilon_2 = 0$, $g_2 = 0.1\text{cm}^{-1}$. (4) $W,D,C(g_1)$. Profile $\rho_{33}(\varepsilon_2)$, $\varepsilon_1 - 0$, $g_2 = 0.1\text{cm}^{-1}$. For all cases $\Gamma = 10^{-7}\text{cm}^{-1}$, $\Gamma_1 = \Gamma_2 = 0$. $\gamma = 10^{-3}\text{ cm}^{-1}$, $\gamma_1 = 0.9\gamma$, $\gamma_2 = 0.1\gamma$.

$\Gamma_{1,2}$ being the equal to each other and being more on order then spontaneous decay rates. The decay rates of the low-frequency coherency Γ are more on two orders then Γ_1, Γ_2. The results of the computer simulation for the strong radiation fields are shown in Fig. 5. Here one of two Rabi frequencies is fixed and the other one changes. The widths are measured both on $\rho_{33}(\varepsilon_1)$ and on $\rho_{33}(\varepsilon_2)$. We see that the characteristics of the resonance on the profiles $\rho_{33}(\varepsilon_1)$ and $\rho_{33}(\varepsilon_2)$ are the same when $g_1 = g_2$, i.e. the asymmetry is absent. The equality of the decay rates of the upper level population on the neighboring optical transition manifests itself as a coincidence of the curves (1) and (3), (2) and (4). When $g_1 \neq g_2$ the smaller width is observed on the profile $\rho_{33}(\varepsilon_i)$ where ε_i is the detuning of the radiation field that is resonant to the transition with the smaller Rabi frequency. Note that the relation $[W \text{ for } \rho_{33}(\varepsilon_2)]/[W \text{ for } \rho_{33}(\varepsilon_1)]$ provides the information about the ratio of the electric dipole moments of the optical transitions that are coupled by the field. Furthermore, the small decrement of the depth that observed when the Rabi frequency is decreased to $g_i \sim 0.01\text{ cm}^{-1}$ appears because of violation of the saturation conditions since the decay rates are large. The discussed figure is obtained for the strong radiation fields and we observe that the curves $W(g_{1,2})$ have a minimum, i.e. the situation is possible when the decreasing of the width is observed while the one of the Rabi frequencies is increased and the other one is constant. As we will show below this effect is absent in the weak fields.

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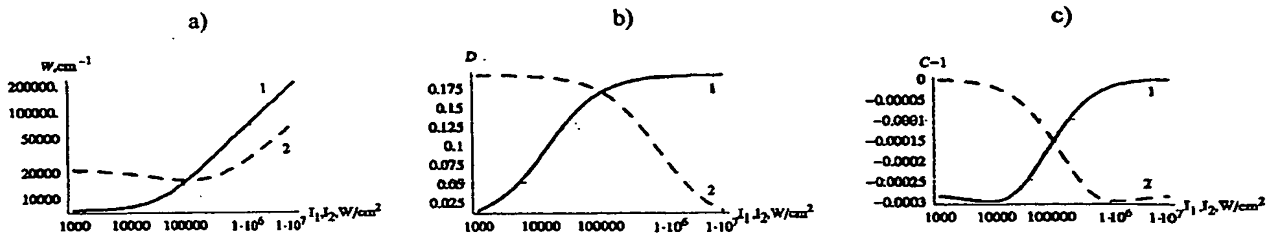

Fig. 7. The dependence of the width (a), depth (b) and contrast (c) of CPT-resonance on the intensity of the one of the radiation fields for Tl atom. Resonance is considered on the profile $\rho_{33}(H)$. $\varepsilon_1 = \varepsilon_2 = 0$. (1) $W,D,C\,(I_{L2})$, $I_{L1} = 10^5\,\mathrm{W/cm^2}$. (2) $W,D,C\,(I_{L1})$, $I_{L2} = 10^5\,\mathrm{W/cm^2}$. For all cases $\Gamma = 10^{-7}\,\mathrm{cm^{-1}}$, $\Gamma_1 = \Gamma_2 = 0$. $\gamma = 4\cdot 10^{-3}\,\mathrm{cm^{-1}}$, $\gamma_1 = 0.33\gamma$, $\gamma_2 = 0.38\gamma$.

Figure 6 is as Fig. 5, but when the partial spontaneous decay rates are unequal for the considered optical transitions. Presence of the asymmetry both of the Rabi frequencies and of the spontaneous decay rates results in the appearance of four different curves (compare with Fig. 5) and the relative positions of the curves depends on the ratio γ_2/γ_1. Hence one can not detect the general conditions for the widest, the narrowest or the deepest CPT-resonance.

As discussed by Kocharovskaya in [4] when the dipole moment for one of the transitions of a system tents to zero the low frequency coherency is rather absent and there is no CPT. However, as predicted theoretically in this work for the three level system with the unequal electric dipole moments interacting with the periodic sequence of the pulses, the small decreasing of the dipole moment on the one of the transitions results not in the decreasing but in the increasing of the CPT-resonance depth. Then, the further decrement causes the decrement of the depth. In Fig. 6(b) we observe the similar effect: There is a growth of the depth measured on the profile $\rho_{33}(\varepsilon_2)$ when g_2 decreases in comparison with g_1 (the curve (1)) or when g_1 increases in comparison with g_2 (the curve (2)).

If the media is brought to the CPT-state, the dependences of the fluorescence intensity on the magnetic field strength has a dip at the zero and named in [6, 7] as CPT-resonance. Existence of this effect is explained by the inequality of the magnetic dipole moments of the states that are coupled by the radiation field. We consider CPT of this type on the profile $\rho_{33}(H)$ for the system of levels of Tl atom. The partial spontaneous decay rates are taken proportional to the squared electrical dipole moments for the considered transitions. In Fig. 7 the width and depth of the dip in shown versus the intensity of the one of the radiation fields when the other intensity is constant. One sees that these dependencies are similar to the dependencies obtained on the profiles $\rho_{33}(\varepsilon_{1,2})$. This in particular gives the possibility to reveal the asymmetry of the characteristics of the optical transitions.

Renzoni et al [7] suggest to utilize the CPT-resonance observed in the weak radiation fields in the magnetometry of the weak magnetic fields with values of the order 1 G. Thereby, the CPT-resonance observed in the strong fields for the fine structure levels of Tl atom is possible to use for measuring of the magnetic field strength in wide band of values. The width of the band depends on the intensity of the radiation fields. As seen from Fig. 7 changing the intensity of the radiation fields one can tune the width of the resonance.

Let us now consider the weak radiation fields. In Fig. 8 we show the influence of the asymmetry of the optical transitions on the characteristics of the CPT-resonance in this case. We detect that when the intensity is in the region $W \sim g^2, I_L$, see Fig. 2, (for example, at decay rates $\gamma = 10^{-3}\,\mathrm{cm^{-1}}$ the frequencies $g_{i,j} = 10^{-6}, 10^{-4}\,\mathrm{cm^{-1}}$ belong to this range) the width and the contrast are insensitive to the asymmetry given as by unequal partial decay rates as by unequal dipole moments. The depth is found to be responsive to the inequality of the spontaneous decay rates. The deepest resonance takes place when the larger Rabi frequency corresponds to the transition with larger partial decay rate. This is independent on the profile that we measure. In addition, the increasing of the intensity of any of the radiation fields results in the increasing of the depth. To explain this we note that the system is far from the saturation for the considered parameter values and the depth may be treated as a difference between the populations of the upper levels of atoms when the only one of the atoms is in the CPT

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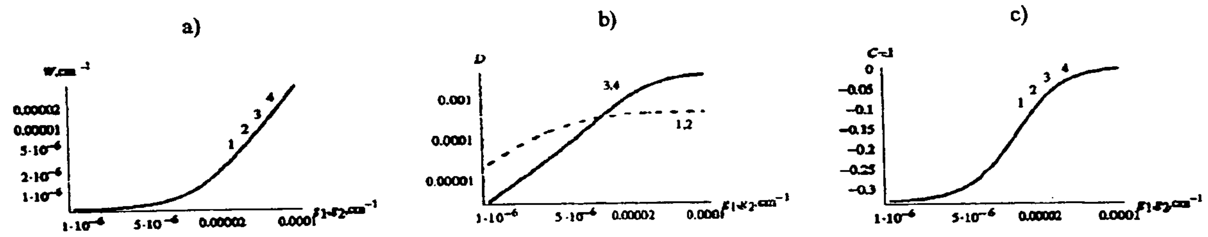

Fig. 8. The dependence of the width (a), depth (b) and contrast (c) of CPT-resonance on the Rabi frequency of the one of the optical transitions for the laser radiation fields with small intensities. Curves (1), (2), (3), (4) are founded in the same manner as in Fig. 6. $g_{1,2} = 10^{-5}\mathrm{cm}^{-1}$, $g_{2,1}$ is changed. For all cases $\Gamma = 10^{-7}\mathrm{cm}^{-1}$, $\Gamma_1 = \Gamma_2 = 0$. $\gamma = 10^{-3}$ cm^{-1}, $\gamma_1 = 0.9\gamma$, $\gamma_2 = 0.1\gamma$.

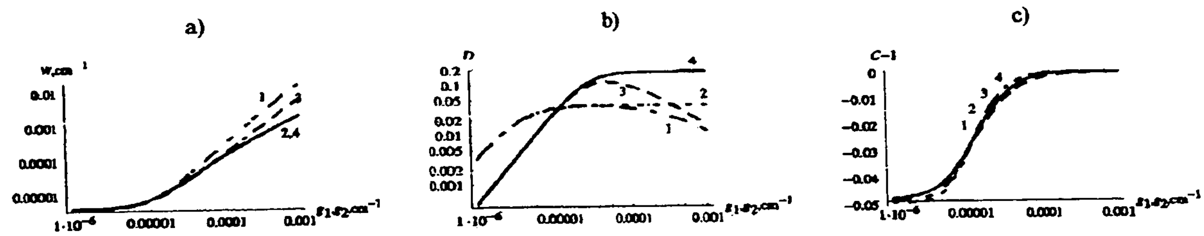

Fig. 9. The dependence of the width (a), depth (b) and contrast (c) of CPT-resonance on the Rabi frequency of the one of the optical transitions when the radiation fields are weak. Curves (1), (2), (3), (4) are obtained the similar as in Fig. 6. $g_{1,2} = 10^{-5}\mathrm{cm}^{-1}$, $g_{2,1}$ is varied. For all cases $\Gamma = 10^{-7}\mathrm{cm}^{-1}$, $\Gamma_1 = \Gamma_2 = 0$. $\gamma = 10^{-4}$ cm^{-1}, $\gamma_1 = 0.9\gamma$, $\gamma_2 = 0.1\gamma$.

state while the other one is not in this state. Hence behavior of the depth is determined by the behavior of the population of the upper state of the second atom.

When the intensity of the one of the radiation fields corresponds to the region $W \sim g, I_L^{0.5}$, see Fig. 2, the considered characteristics of the CPT-resonance are responsive to the asymmetry as seen in Fig. 9. For example if the spontaneous decay rate is about $\gamma \sim 10^{-4}, 10^{-5}\,\mathrm{cm}^{-1}$, the influence of the asymmetry is observed at the Rabi frequency on the one of the transitions about $g \sim 10^{-4}\,\mathrm{cm}^{-1}$. For smaller Rabi frequency the characteristics are rather insensitive to the asymmetry.

We showed that the width, depth and contrast of the dip of the CPT-resonance in the strong fields are sensitive to the asymmetry of the optical transition, while for the weak fields the sensitivity is rather absent. Hence the CPT-resonance can be utilized as a tool for measuring of the parameters of the asymmetry of the optical transitions.

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